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ON THE NATURE OF CERTAIN BACKGROUND RADIATION

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ABSTRACT: In the first part of this paper, possible sources of the sub-millimeter background of large intensity observed by Harwit et al. in the metagalaxy, the galaxy, and the terrestrial atmosphere are discussed. It is shown that the most natural assumptions about the sources of this background encounter significant difficulties.

In the second part, the model proposed by Hayakawa and Silk-McGray, which is based on the assumption that the background is produced by bremsstrahlug of photons with metagalactic sub-cosmic rays, is analyzed.

It is shown that such a model leads to too large values of the temperature of the intergalactic gas and the intensity of photons and, consequently, should be rejected.

I. Comment on the Nature of the Infrared Background

In the papers [1,2] the results of observation of the background in the sub-millimeter region (λ = 0.4 - 1.3 mm). are presented. The significant density of the radiation flux ($\sim 5 \times 10^{-9}$ watts cm^{-2} ster^{-1}) allowed the authors to interpret it as a manifestation of metagalactic radiation with $T \sim 8^{\circ}$K. /3*

The task of the present communication is to present a critical analysis of the possible sources of this radiation.

a) Intergalactic origin of the background

1. An investigation of the absorption spectra of CN and CH molecules in this range of wavelengths shows that at λ = 0.56 mm, $T < 5.9°$ but at λ = 1.3 mm, $T < 4.7°$ [3].

One can combine the results of [1,2] and [3] at the price of artificial assumptions that the source of the sub-millimeter background has a very narrow spectral distribution ($\Delta\lambda \ll 0.5$ mm; $\frac{\Delta\lambda}{\lambda} \ll 0.5$) and is located in the narrow range of distances $\Delta Z \ll 0.5$. /4

2. The difficulties grow even greater in explaining the absence of a steep drop in the energy spectrum of cosmic rays at an energy greater than

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* . Numbers in the margins indicates pagination in the foreign test.

10^{19} eV [4,5]. The most natural assumption in this case is that such cosmic rays arise in the nearby vicinity of the galaxy (where there are no visible sources of these radiations) or inside the galaxy when it is difficult to find a mechanism to contain them.

Unfortunately now the experimental data on sources in this region are too scarce to reply to this question in any sort of definite way. Evidently, the maximum radiation of the normal galaxies lies in the optical region and, consequently, it is rejected as a possible source.

A more complicated question concerns the role of Seyfert galaxies and quasars. In some of these objects the maximum radiation occurs in the submillimeter region. We made an estimate of the possible background from quasars, assuming that they all radiate similar to the quasar 3C273 (where radiation in the submillimeter region is observed), and assuming that all quasars radiate identically and that their density is distributed according to Schmidt [6].

$$n_K(z) = n_0 (1+z)^{3+\beta}$$
$$n_0 = 10^{-8} (M\mathrm{pc})^{-3} \qquad \beta = 7 \tag{1}$$

Such an estimate, evidently, is rather an upper limit, but it gives a /5
value of the infrared background approximately two times larger than was observed in the paper [1,2][1].

We note that these estimates lead to a large value of the background in the infrared region ($\lambda \sim 10$-$100\ \mu$). If they are valid, then the situation should be expressed in the form of the spectrum of the relict radiation and the spectrum of the metagalactic cosmic rays of very high energies ($\gtrsim 10^{15}$ eV).

b) Galactic origin of the background

1. We note that the possible sources of the background cannot be dis-

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1. Similar estimates relative to the role of Seyfert galaxies led to the same results [7]. The more recent results of Low [6] can scarcely refine the conclusions [7].

tributed exclusively inside the galactic disk, since in this case the anisotropy of the radiation would be too great. It is necessary to assume a significant density in the halo[2].

2. We discuss the problem of the connection of galactic electrons with the infrared background. The average strength of the magnetic field in the galaxy is $\lesssim 5\cdot10^{-6}$ oersted and at least 3-4 times smaller in the halo [8]. Then the losses of relativistic electrons in the inverse Compton effect /6
process with the submillimeter radiation should exceed by approximately 30 times their losses by synchrotron radiation. Then the power of injection of electrons reaches the value $\sim 10^{40}$ ergs sec^{-1} [9].

The energies of supernovae are sufficient only for the injection of electrons with a total power of $\sim 10^{38}$ ergs sec^{-1} [9].

Disruptive processes in the center of the galaxy cannot contribute the main portion to the generation of electrons since in this case electrons with an energy $\gtrsim 10^{11}$ eV, observed in an experiment [10], cannot reach the earth.

3. There is observed a sharp break in the energy spectrum of cosmic electrons at energies of $\sim$ 3-5 GeV. This sharp break is well explained by an energy corresponding to equality of the electrons' lifetime with respect to their exit from the galaxy with the lifetime relative to losses by synchroton radiation [11]. The strong submillimeter background decreases the lifetime with respect to losses by a factor of 30 and, consequently, a sharp break should be observed at energies of $\sim$ 100 MeV.

c) Atmospheric origin of the background

The main sources of submillimeter radiation background in the atmosphere are, evidently, rotational electric-dipole transitions of NO molecules and the magnetic-dipole transition in O_2 molecules.

In agreement with the reference data [12-14] the distribution of the /7
temperature T and the concentrations of O_2 and NO with height h has the following form:

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2. Recently the existence of the halo has been subject to doubt.

TABLE I

h (KM)	n (CM^{-3})	n_{O_2} (CM^{-3})	n_{NO} (CM^{-3})	T^0K
120	$3 \cdot 10^{12}$	$7 \cdot 10^{10}$	10^6	300
150	$3 \cdot 10^{10}$	$3 \cdot 10^9$	10^7	900
180	10^{10}	$8 \cdot 10^8$	$2 \cdot 10^6$	1100
200	$7 \cdot 10^9$	$4 \cdot 10^2$	10^6	1200
300	10^9	$2 \cdot 10^7$	10^5	1300
400	$2 \cdot 10^8$	$2 \cdot 10^6$	-	1300

A calculation of the intensity of the radiation from NO and O_2 molecules is carried out by several different methods. For brevity we dwell in more detail on the calculation of the radiation intensity of NO molecules.

The flux of quanta with a frequency corresponding to the $J \rightarrow J - 1$ transition is equal, with a high degree of accuracy, to:

$$F(J) = \int_{h_H}^{\infty} n(h) W_J(h) \hbar \omega_J A_J \, dh, \qquad (2)$$

where n(h) is the concentration of molecules : W_J is the probability of /8
finding a molecule in the J level, A_J is the probability of the $J \rightarrow J - 1$ transition, and n_H is the level at which the observations are carried out. The transition probability for an NO molecule is given by the expression:

$$A_J = \frac{4}{3} \frac{\omega_J^3}{\hbar c^3} d^2 \frac{J^2 - 1}{J(2J+1)}, \qquad (3)$$

where d is the dipole moment.

The frequency w_J is determined from the equality:

$$\omega_J = 2BJ, \tag{4}$$

where the rotational constant is $B = 3.2 \times 10^{11}$ hertz.

Then it turns out that J = 2-7 corresponds to the interval 0.4 to 1.3 mm. We take the distribution of W_J in the form of the Boltzmann function:

$$W_J = \frac{2J+1}{kT} \hbar B\, e^{-\frac{\hbar BJ(J+1)}{kT}}. \tag{5}$$

The following discussion serves as the basis for using the distribution (5). In agreement with [15] the Boltzmann distribution in this range of energies is adjusted if the number of collisions is $\gtrsim 10$ during leaking of the levels. Using this result and also the distribution of the concentration presented in Table 1, one obtains the fact that up to heights $\lesssim 400$ km the distribution of levels has the form (5). /9

It is necessary, strictly speaking, to take into consideration the dependence of W_J on T (h) in calculating the integral (2). One can as a simplification (see Table 1) set T = 1000° K with a sufficient degree of accuracy.

Then, after summing over J, we obtain $F_{NO} \sim 10^{-11}$ watts cm^{-2} $ster^{-1}$ at an altitude of 120 km and $F_{NO} \sim 10^{-12}$ $ster^{-1}$ at an altitude of 120 km [sic]. The intensity of the O_2 lines is approximately 1.5 times greater.

And so in spite of the crudeness of our estimates, one can assume that the contribution of atmospheric radiations is significantly smaller than the observed flux.

The authors express their appreciation to I.D. Nivikov for useful comments.

II. On the "Bremsstrahlung" Model of the Roentgen Background

Recently papers have appeared which explain the isotropic roentgen /10
background by bremsstrahlung of soft photons by slow metagalactic electrons[3].

The winning factor of this model is its natural explanation of the sharp break in the energy spectrum of the isotropic roentgen background in the region $E_\gamma \sim$ 20-60 KeV. Hayakawa [3] proposed a mechanism for the formation of roentgen photons by sub-cosmic rays upon their interaction with the thermal intergalactic electrons (inner bremsstrahlung). Silk and McGray [4] discussed the interaction of sub-cosmic electrons with the intergalactic plasma.

We note that, although externally these models appear different, in /11
reality one and the same process of the emission of photons by electrons lies at their foundation. The difference (which is not of a fundamental nature) consists in the fact that in the paper [3] the chosen system of coordinates (metagalaxy) coincides with the electrons but in paper [4] it coincides with the protons.

We note that the quantitative difference is practically absent for the non-relativistic case of interest to us (i.e., when the speed of the incident protons and electrons are, respectively, $v_p \ll c$ and $v_e \ll c$). In the relativistic case the quantitative properties are different. In the non-relativistic limit the differential cross section $d\sigma_\gamma$ of the emission of a quantum with an energy in the range E_γ, $E_\gamma + dE_\gamma$ upon collision of a proton and an electron is equal to [5].

$$d\sigma_\gamma \approx \frac{16}{3}\frac{1}{137}\left(\frac{e^2}{m_e c^2}\right)^2\left(\frac{c}{v}\right)^2\frac{dE_\gamma}{E_\gamma}\ln\frac{4E_e}{E_\gamma}, \qquad (1)$$

where v is the relative velocity and E_e and E_γ are the energy of the electron and the photon, respectively.

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3. This mechanism as applied to galactic electrons was discussed long ago [1,2]. One should reject such a model because of its disagreement with the new experimental data on the angular distribution and intensity of the roentgen background.

It is evident from (1) that the cross section does not depend on which particle (the electron or the proton) is at rest.

Eq. (1) is valid, strictly speaking, in the non-relativistic limit; we will use it for energies up to $E_e \sim m_e c^2$, which is completely justified by the (logarithmic) accuracy with which we will usually carry out the calculations.

Later we will formulate the main point of our paper. We assume that /12 the "bremsstrahlung" hypothesis results in exceedingly large values of the roentgen radiation, and to a non-power energy spectrum of the radiation in the region $E_\gamma \gtrsim 100$ KeV.

The proof of these assertions will be broken into two stages. In the first stage, semi-quantitative estimates as applied to the electron version [4] (the electrons collide with the stationary protons) will be given. In the second stage more rigorous calculations for the proton version (here the electrons are stationary) [3] will be given.

Such a division is suitable for the following reasons:

1) data is lacking in the paper [3] concerning the fundamental nature of the phenomenon -- the energy spectrum of the sub-cosmic protons;

2) the estimates permit tracing clearly the physics of the phenomenon; and

3) the conclusions in both versions differ somewhat because of the red shift.

I. <u>Electron Version</u>

In the paper [4] there is discussed a model mainly where all the sub-cosmic electrons have appeared at a certain $z = z_i$. Then the electric spectrum $F_e\ (E_e, z)$ of the electrons at a distance z has the form:

$$F_e(E_e,z) = K_e E_e^{-\gamma_e} \left(\frac{1+z}{1+z_i}\right)^{2(\gamma_e+1)} \times$$

$$\times \left\{1 + \frac{3}{2}\left(\frac{E_{ec}}{E_e}\right)^{3/2} \frac{(1+z)^2}{1+z_i}(1+z)^{4/3}\right\}^{-\frac{2}{3}(\gamma_e+1)} \frac{\text{particles}}{\text{cm}^2\ \text{sec ster KeV}} \qquad (2)$$

where $K_e \sim 10^{11}$ (E_e in KeV); $\gamma_e = 2.5$; $z_i = 10$; $E_{ec} = 100$ KeV; the density of the material at our epoch is $\rho_o \sim 10^{-31}$ gm cm^{-3}. We then calculate L_t - the energy released in the ionization process by the spectrum (2) per unit time.

$$L_t(z) = -\int_{E_{e\,min}}^{m_e c^2} dE_e F_e(E_e, z) \frac{dE_e}{dt} \; ; \qquad (3)$$

$$-\frac{dE_e}{dt} = 8 \cdot 10^9 n(z) \sqrt{\frac{2 m_e c^2}{E_e}} \, B \; \frac{\text{eV}}{\text{sec}} \qquad (4)$$

(see [6]), where $n(z) = n_o (1 + z)^3$ is the electron concentration in the intergalactic gas; $B \sim 40$ (to logarithmic accuracy); $E_{min} \sim kT$. Since an accurate value of the upper limit in (3) is immaterial, we set it equal to $m_e c^2$.

In order to calculate the temperature T it is necessary to investigate the kinetics of the thermal balance [7]. However, since in this section only the boundaries for values of T are being estimated, we are restricted to a comparison of the separate terms of the kinetic equation. Cooling of the intergalactic plasma is caused by three processes: the red shift (e); the Compton effect on the relict radiation (c), and the radiation of the intergalactic plasma (τ). The heat emission of a unit volume in one second corresponding to these processes has the form [8]: /14

$$L_{e-} \sim 3 \cdot 10^{-38} \frac{\rho_o}{\rho_c} T (1+z)^4 \sqrt{1 + \frac{\rho_o}{\rho_c} z} \; , \qquad (5a)$$

$$L_{c-} \sim \frac{\rho_o}{\rho_c} 10^{-40} T (1+z)^7 \quad \frac{\text{ergs}}{\text{cm}^3 \text{ sec}} \; , \qquad (5b)$$

$$L_{\tau-} \sim 5 \cdot 10^{-33} \left(\frac{\rho_o}{\rho_c}\right)^2 \left(\frac{T}{10^7}\right)^{1/2} (1+z)^6 \; , \qquad (5c)$$

where $\rho_c \sim 10^{-29}$ gm cm^{-3} is the critical density; Eq. (5c) is valid for $T \gtrsim (10^7)$° K.

The relations L (z) calculated in agreement with (3) to (5) at $T = (10^9)$°K are presented in Table 1.

z	L_+	L_{e-}	L_{c-}	$L_{\tau-}$
	ergs cm^{-3} sec^{-1}			
0	$5 \cdot 10^{-29}$	10^{-31}	10^{-33}	10^{-36}
2	10^{-29}	$5 \cdot 10^{-30}$	10^{-31}	10^{-34}
5	$5 \cdot 10^{-26}$	10^{-28}	10^{-28}	10^{-32}
8	$5 \cdot 10^{-24}$	10^{-27}	10^{-27}	10^{-31}
$z_i = 10$	10^{-20}	$5 \cdot 10^{-27}$	10^{-26}	10^{-30}

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At $T \lesssim (10^9)$°K, the total heat emission is significantly smaller than the heating produced through ionization by the sub-cosmic elections. Therefore, if the latter are capable of heating the intergalactic gas (without taking into account losses) to $T > (10^9)$°K, then it indicates that the true value of T is $> (10^9)$°K.

The total heating without taking into account the cooling can be easily calculated, using the values of L_t from Table 1. It turns out that in a time $t_{MG} \sim 3 \times 10^{17}$ sec energy in the amount $\sim 10^2$ eV cm^{-3} is released. This indicates that in neglecting the losses $T \sim (10^{13})$°K. This value is the upper limit for values of T.

Thus if sub-cosmic electrons with the energy spectrum (2) exist in the metagalaxy, then the temperature of the metagalactic gas should be contained within the limits (10^9 to 10^{13})°K and there should consequently be radiation /16 in the range (10^5 to 10^9) eV with a non-power quasi-Planckian spectrum.

One can explain this conclusion by simple physical ideas. If a beam of slow electrons which are absorbed in a certain volume are incident upon a plasma, then thermal equilibrium will be established in the volume.

The relaxation time τ can be estimated from the equation:

$$\tau \sim \frac{\sqrt{m_e}}{4\pi} \frac{(kT)^{3/2}}{\lambda n e^4}; \qquad (6)$$

$\lambda \sim \ln \frac{3DkT}{e^2}$; e is the electron charge, and D is the Debye radius [9].

In our case $\lambda \sim 10^2$. Equating $\tau = t_{MG} \sim \frac{1}{H_o}$, we obtain the fact that if $T \lesssim (10^9)$°K, then thermal equilibrium is established.

2. Calculation of the Energy Spectrum of the Cosmic Protons

In this and the following sections the proton version is discussed. We calculate $F_p(E_p, z)\, d E_p$ -- the flux of cosmic protons in the range E_p, $E_p + d E_p$, assuming that the luminosity q of a unit volume in the sources has the power form:

$$q(E_p, z)\,dE_p = K_p E_p^{-\gamma_p} (1+z)^{3+\beta}\, dE_p, \quad z < z_i. \qquad (7)$$ [17]

The constant β takes into account possible evolution of the sources of protons.

Then in agreement with the standard equations of the Friedmann model for $p = p_c$, the flux of protons is

$$F_p(E_p, z) = \frac{(1+z)^3}{4\pi} \frac{v_p}{H_o} \int_z^{z_i} q[E_p'(E_p, z, z'), z'](1+z')^{-5.5} \frac{dE_p'}{dE_p} dz', \qquad (8)$$

where v_p is the velocity of the protons; $E'_p(E_p, z, z')$ is the energy of proton at a point $z' > z$, if the energy observed at the point z is equated to E_p.

We use Eq. (4) to calculate the relation $E'_p(E_p, z, z')$, replacing m_e by m_p. Then the total energy losses caused by ionization and the expansion of the universe are described by the equation:

$$\frac{dE_p}{dz} = \frac{E_p}{1+z} + \frac{dE_p}{dt} \cdot \frac{dt}{dz} \qquad (9)$$

Since

$$\frac{dt}{dz} = -\frac{1}{H_0(1+z)^{2.5}}; \qquad (10)$$

Eq. (4) takes the form: /18

$$\frac{dE_p}{dz} = \frac{2E_p}{1+z} + \sqrt{1+z}\,\frac{E_{pc}^{3/2}}{E_p^{1/2}}. \qquad (11)$$

The critical energy

$$E_{pc} = \left[\frac{5 \cdot 10^{-7} n_0}{H_0} \sqrt{m_p c^2}\right]^{2/3} \sim 15 \text{ MeV} \qquad (12)$$

has a simple physical meaning (see [3], [4]). If $E_p < E_{pc}$, then a proton is retarded at our epoch principally due to ionization losses; if $E_p > E_{pc}$, then the red shift plays the main role.

Eq. (11) has the solution:

$$E_p(E_p', z, z') = E_{pc}(1+z)^2 \left\{ \left[\frac{E_p'}{E_{pc}(1+z)^2}\right]^{3/2} - (1+z)^{-3/2} + (1+z')^{-3/2} \right\}^{2/3} \qquad (13)$$

Using (7), (8), and (13):

$$F_p(E_p, z) = \frac{K_p}{4\pi}\frac{v_p}{H_0} E_p^{0.5} E_{pc}^{-(\gamma_p + 0.5)} \times \qquad (14)$$

$$\times \int_z^{z_i} \frac{(1+x)^{\beta - 2\gamma_p - 0.5}\,dx}{\left\{\left[\frac{E_p}{E_{pc}(1+z)^2}\right]^{3/2} - (1+z)^{-3/2} + (1+x)^{-3/2}\right\}^{\frac{2}{3}(\gamma_p + 0.5)}}.$$

4. In the proton version $\rho_0 = \rho_c$.

The integral (14) is not taken in the general form and therefore we will reduce it to its asymptote. If $E_p \gg E_{pc}(1 + z)^2$, then /19

$$F_p(E_p,z) = \frac{K_p v_p}{4\pi H_0}(1+z)\frac{(1+z_i)^{\beta-2\gamma_p+0.5} - (1+z)^{\beta-2\gamma_p+0.5}}{\beta-2\gamma_p+0.5} \quad (15)$$

If $E_p \ll E_{pc}(1+z)^2$, then

$$F_p(E_p,z) = \frac{2}{2\gamma_p-1}\,\frac{K_p v_p}{4\pi H_0}\,E_p^{1.5-\gamma_p}\,E_{pc}^{-1.5}(1+z)^{\beta} \quad (16)$$

The spectrum of protons in space has a non-power form; the spectral index varies from $\gamma_p - 1.5$ (low energies) to γ_p (high energies).[5]

3. Density of the Sub-cosmic Protons

To estimate the energy density E_p of the sub-cosmic protons we use Eq. (15), which is valid for values of the parameter B which are not too large. For definiteness we set $\beta = 0$.

We write the relation (15) in the form: /20

$$F_p(E_p,z) = A(z)\overset{o}{E}{}_p^{-\gamma_p}\, v_p\, dE_p . \quad (15a)$$

Then the luminosity $q(E_\gamma,z)\,dE_\gamma$ of a unit volume, produced by bremsstrahlung of protons, is equal to:

$$q(E_\gamma,z)\,dE_\gamma = dE_\gamma\, n_e(z) A(z)\int_{\frac{m_p E_\gamma}{m_e}}^{\infty} dE_p\, E_p^{-\gamma_p}\, v_p\, \frac{d\sigma}{dE_\gamma}, \quad (17)$$

where $\frac{d\sigma}{dE_\gamma}$ is determined by (1).

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5. Such a spectrum is the result of thermalization of protons for which, however, the relaxation time $\tau \sim \frac{m_p}{m_e}$ (see [6] and Sect. 1).

After the transformations we obtain:

$$q(E_\gamma, z)\,dE_\gamma = dE_\gamma\, 5\cdot 10^5 n_e A \frac{e^6}{\hbar c^3} \frac{E_\gamma^{-(\gamma_p+0.5)}}{m_e^{3/2}} \times \left(\frac{m_p}{m_e}\right)^{1-\gamma_p} f(\gamma_p), \tag{18}$$

where the function $f(\gamma_p)$ is determined by the logarithm in Eq. (1). In the interval $1 < \gamma_p < 2$ this function is contained within the limits 1 to 5 - 1/3; we set it equal to 1.

Using (8) and (18), we obtain that

$$F_\gamma(E_\gamma) = 10^{23} K E_\gamma^{-(\gamma_p+0.5)} \frac{1}{2\gamma_p-0.5} \times \left\{ \frac{1-(1+z_i)^{-3\gamma_p+0.5}}{3\gamma_p-0.5} + \frac{(1+z_i)^{-2\gamma_p+0.5}\,[(1+z_i)^{-\gamma_p}-1]}{\gamma_p} \right\}. \tag{19}$$

We combine this expression with the experimental value for the flux of roentgen /21 radiation in the region $E_\gamma \gtrsim 50$ KeV, $F_\gamma(E_\gamma,\ z = 0) \approx 60^{-2.2\pm0.2}$ photons cm^{-2} sec^{-1} $ster^{-1}$ KeV^{-1} (see, for example, [4]).

It follows from the combination of (19) and (20) that $\gamma_p = 1.7$; $K \sim 10^{-20}$ (E_γ in units of KeV; $z_i \gg 1$) and the energy density of protons E_p $(z = 0) \sim 10$ eV cm^{-3}, which is an inadmissibly high number.

The only possibility of decreasing it is to assume very large values of $\beta \gg 1$. When $\beta \to \infty$ in the integral (14) the upper limit is important; therefore;

$$F_p(E_p, z) = \frac{n_p v_p}{4\pi H_0} E_p^{-\gamma_p} (1+z)^3 \times \frac{z_i^{\beta-2\gamma_p+0.5} - z^{\beta-2\gamma_p+0.5}}{\beta-2\gamma_p+0.5}. \tag{20}$$

Using the procedure noted above, it is not difficult to determine that for this set-up the energy density of protons is

$$\mathcal{E}'_p(z=0) \sim \mathcal{E}_p(z=0)(1+z_i)^{-2\gamma_p} \; ; \quad \text{for} \quad \gamma_p = 1.7,$$

$$z_i = 10 \qquad \mathcal{E}'_p \sim 10^{-3} \div 10^{-2} \; \frac{\text{eV}}{\text{cm}^3}.$$

4. Heading of the Intergalactic Gas by Sub-cosmic Protons

The integral

$$L_+ = 4\pi \int_0^\infty \frac{dE_p}{dt} \, \frac{F(E_p, z)}{v_p} \, dE_p. \tag{21}$$ /22

determines the function L_t for sub-cosmic protons. Using (4) and (14):

$$L_+ = 5 \cdot 10^{-24} (1+z)^5 \, \frac{K E_0^{-(\gamma_p - 0.5)}}{H_0} \sqrt{m_p c^2} \cdot \frac{\Gamma\left(\frac{5}{3}\right) \Gamma\left(\frac{2\gamma_p - 1}{3}\right)}{\Gamma\left(\frac{2\gamma_p + 1}{3}\right)} \times$$

$$\times \int_0^{(1+z)^{-3/2} - (1+z_i)^{-3/2}} dy \, \frac{\left[(1+z)^{-3/2} - y\right]^{-\frac{2}{3}(\beta - 2\gamma_p + 2)}}{y^{\frac{2\gamma_p - 1}{3}}}, \tag{22}$$

where Γ is the gamma function.

We carry out the calculations for the most suitable parameters $\gamma_p = 1.75$ and $\beta = 1.5$. Then

$$L_+ = 3 \cdot 10^{-23} (1+z)^5 \, \frac{K E_0^{-(\gamma_p - 0.5)} \sqrt{m_p c^2}}{H_0} \, \frac{\Gamma\left(\frac{5}{3}\right)\Gamma\left(\frac{5}{6}\right)}{\Gamma\left(\frac{3}{2}\right)} \times$$

$$\times \left[(1+z)^{-3/2} - (1+z_i)^{-3/2}\right]^{1/6} \; \frac{\text{ergs}}{\text{cm}^3 \, \text{sec}}. \tag{23}$$

Using (19) and (20) to determine K, one can write:

$$L_+ \sim 10^{-28} (1+z)^5 \left[(1+z)^{-3/2} - (1+z_i)^{-3/2}\right]^{1/6} \; \frac{\text{ergs}}{\text{cm}^3 \, \text{sec}}. \tag{24}$$

For $z \ll z_i$, this value agrees approximately with the value of the electron version (see Table 1). It follows from Table 1 that if $z < 10$, then the main process of heat transfer in the universe is its expansion. Therefore, for an approximate calculation of the run of the temperature we use the equation of thermal balance discussed in the paper [7]. /23

$$-\frac{3}{2}\rho^{5/2}\frac{dT}{d\rho}+\rho^{3/2}T=\frac{L}{2.5\cdot 10^5} \quad (25)$$

If T = 0 at $z = z_i$, then

$$T \sim 2\cdot 10^9\left[(1+z)^{-1.75}-(1+z_i)^{-1.75}\right]. \quad (26)$$

at $z \lesssim 1$, $T \sim (10^9)\,°K$, which is found to be in good agreement with the estimates of Sect. 1. We note that because of the fact that the density p_0 in the proton version is approximately two orders of magnitude larger than in the electron version, the temperature in the latter model should be significantly higher than in the proton version.

We calculate in accordance with (5c), (8), and (26) the flux of roentgen radiation produced by free-free transitions of the heated intergalactic gas:

$$F_\gamma(E_\gamma)\sim\frac{16}{E_\gamma}\int_0^{z_i}(1+z)^{1.37}e^{-\frac{E_\gamma(1+z)^{2.75}}{kT_0}}dz \quad (27)$$

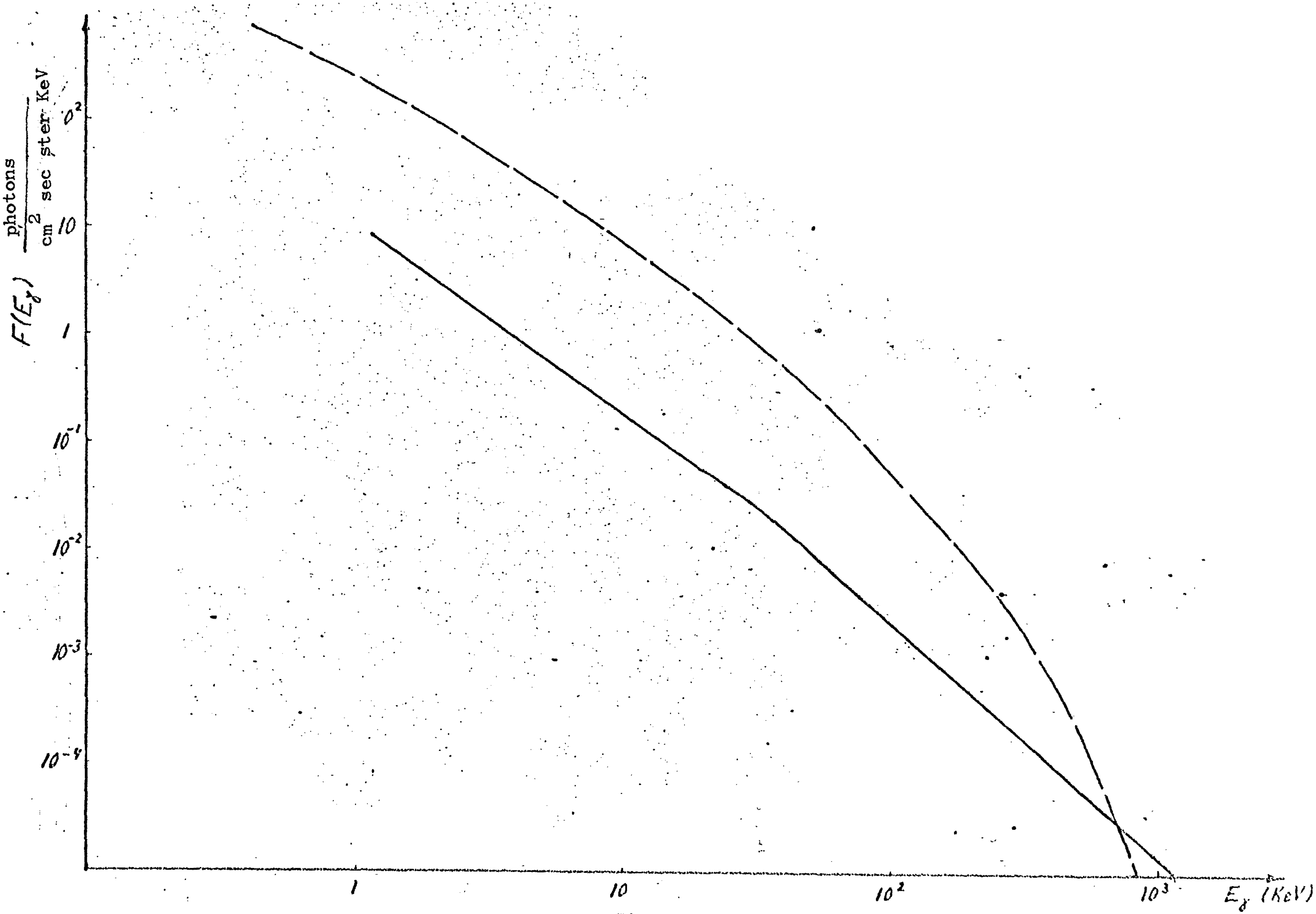
$$kT_0 = 180 \text{ KeV}$$

The experimental spectrum of roentgen radiation which corresponds to the indirect emission by sub-cosmic protons (solid line) and the emission of the heated gas according to Eq. (27) (dotted line) are presented in Fig. 1. /24

Thus if a powerful flux of sub-cosmic protons were to exist, then the roentgen quanta formed by them would in the first place be caused by the heating and emission of the gas.

The assumption of strong evolution ($\beta \ll 1$) does not improve matters here. This situation is clarified in the following way. Let the flux of roentgen radiation be specified experimentally. The ratio of the energy produced by heating to the energy emerging as roentgen because of bremsstrahlung is $\sim \frac{dE/dt}{dE_\gamma/dt}$, where $\frac{dE}{dt}$ is determined by (4) and $\frac{dE_\gamma}{dt}$ the energy losses by bremsstrahlung) is determined by the cross section (1); this ratio does not depend on the density of the gas.

The fraction of energy emerging through emission of the heated gas is $\sim \frac{L_\gamma}{L_+} \sim \rho$; in the case of large evolution and a specified intensity $\frac{dE_\gamma}{dt}$



$F(E_\gamma)$ $\frac{\text{photons}}{\text{cm}^2 \text{ sec ster KeV}}$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
10^3
E_γ (KeV)

Figure 1.

(experimental data) the effective value of p' is a maximum and therefore in this case the curve corresponding to the emission of the heated gas will lie still higher than shown in Fig. 1.

5. Conclusion

/25

Our analysis has shown that in the "bremsstrahlung" model a) the temperature of the intergalactic gas is too high, $\gtrsim (10^8$ to $10^9)$ °K; b) if we do not assume the evolution of the sources to be very great, the energy density of the sub-cosmic rays is inadmissibly large; c) the heated gas will radiate significantly more than in the indirect process of the braking of sub-cosmic rays; and d) the spectrum of the emission by the heated gas will have essentially a non-power shape.

These conclusions lead to the necessity of giving up the "bremsstrahlung" model of the roentgen background.

REFERENCES I

1. Shivandaran, R., Houck, J., Harwitt, M., Phys. Rev. Lett., 21, 1968, p. 1460.

2. Houck, J., Harwitt, M., Astrophys. J. Lett., 157, 1969, L45.

3. Bortolot, V.J., Clauser, J.E., Thaddeus, P., Phys. Rev. Lett., 22, 1969, p. 307.

4. Berezinskiy, V.S., Zatsepin, G.T., Yadernaya Fizika, 10, 1969, p. 1228.

5. Rozental', I.L, Preprint IKI, No. 2, 1969.

6. Schmidt, M., Astrophys. J., 151, 1968, p. 393.

7. Low, F.J., Tucker, W.H., Phys. Rev. Lett., 21, 1969, p. 1538.

8. Pikel'ner, S.B., Kaplan, S.A., Mezhsvezdnaya sreda [The Interstellar Medium], Fizmatgiz, Moscow, 1969.

9. Shkovskiy, I.S. Sverkhnovyye zvezdy [Supernovae], "Nauka" Press, 1966.

10. Rubtsov, V.I., Zatsepin, V.I. Can.Journ.Phys., 46, 1968, p. 518.

11. Dogel', V.A., Syrovatskiy, S.I. Trudy 6 shkoly po kosmofizike [Proceedings of the Sixth School on Cosmic Physics], Part II, p. 49. Apatity, 1969.

12. Okolozemnoye kosmicheskoye prostranstvo. Spravochnyye dannyye [Near-Earth Cosmic Space, Informational Data] "Mir" Press, Moscow, 1966.

13. Nicole, M., Aeronomiya [Aeronomy], "Mir" Press, Moscow, 1964.

14. Bart, Ch. V sb. Elementarnyye protsessy v verkhney atmosfere [IN: Elementary Processes in the Upper Atmosphere], "Mir" Press, Moscow, 1965.

15. Braut, R., J. Chem. Phys., 22, 1954, p. 1189.

16. Low, F.J., Astrophys. J., 159, 1970, L173.

REFERENCES II

1. Hayakawa, S., Matsuoka, M., Suppl. Progr. Theor. Phys., 30, 1964, p. 206.

2. Rozental', I.L., Kosmicheskiye Issledovaniya, 4, 1966, p. 404.

3. Hayakawa, S., Progr. Theor. Phys., 41, 1969, p. 1592.

4. Silk, J., McCrucy, R., Astrophys. Lett., 3, 1969, p. 59.

5. Berestetskiy, V.B., Lifshits, E.M., Pitayevskiy, L.P., Relyativistskaya kvantovaya mekhanika [Relativistic Quantum Mechanics], Chapter 1, "Nauka" Press, Moscow, 1968.

6. Ginzburg, V.L., Syrovatskiy, S.I., Proiskhozhdeniye kosmicheskikh lutey [The Origin of Cosmic Rays], USSR Academy of Sciences Press, Moscow, 1963.

7. Ginzburg, V.L., Ozernoy, L.M., Astronomicheskiy zhurnal, 42, 1965, p.943.

8. Doroshkevich, A.G., Syunyayev, R.A., Astronom., 46, 1969, p. 20.

9. Trubnikov, B.A., V sb.: Voprosy teorii plazmy [IN: Problems in Plasma Theory], Atomizdat, Moscow, 1963. p. 98.

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